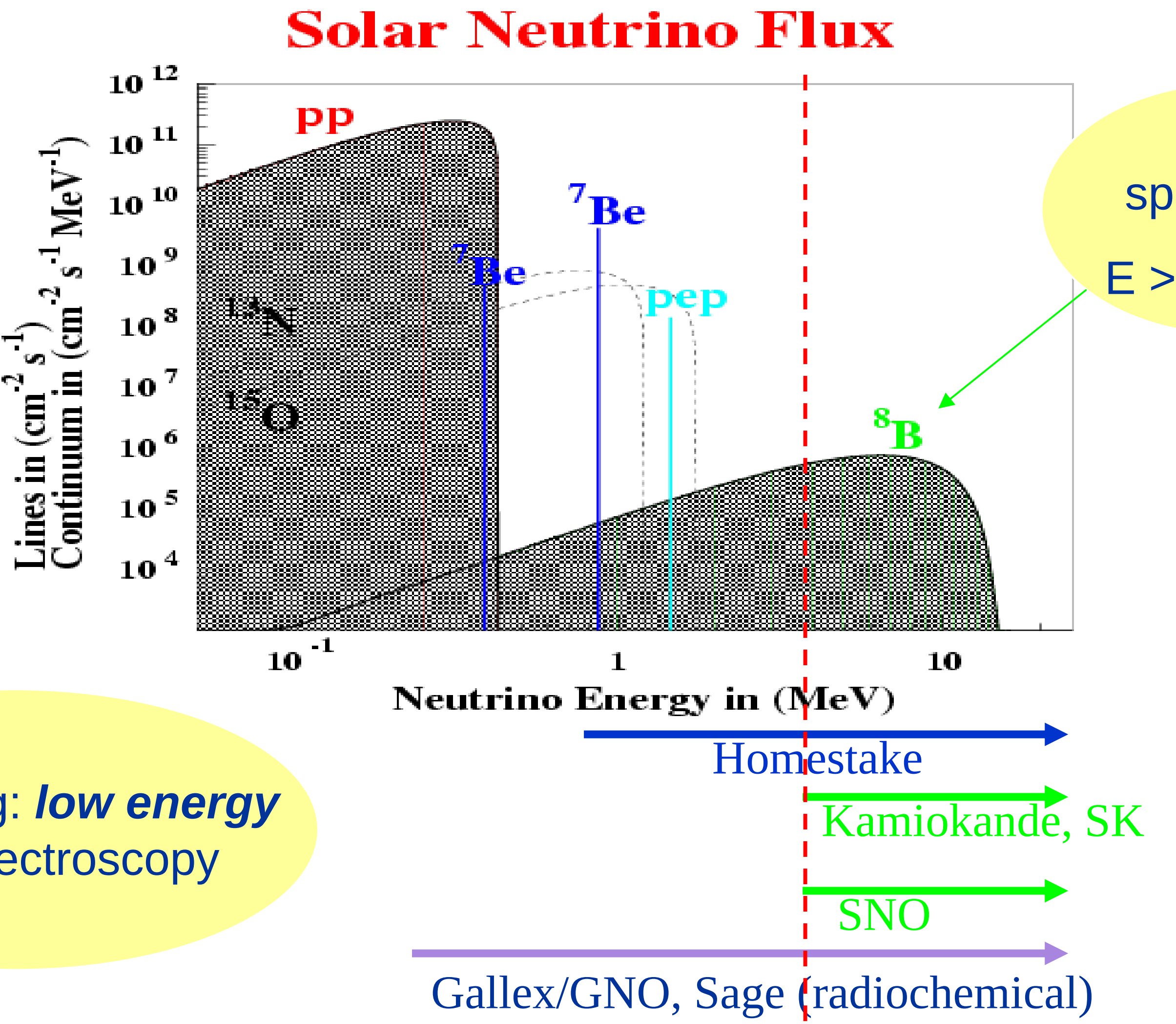
Solar neutrinos

Status and prospects

Solar ν spectrum and experiments with data



Homestake

Kamiokande, SK

SNO

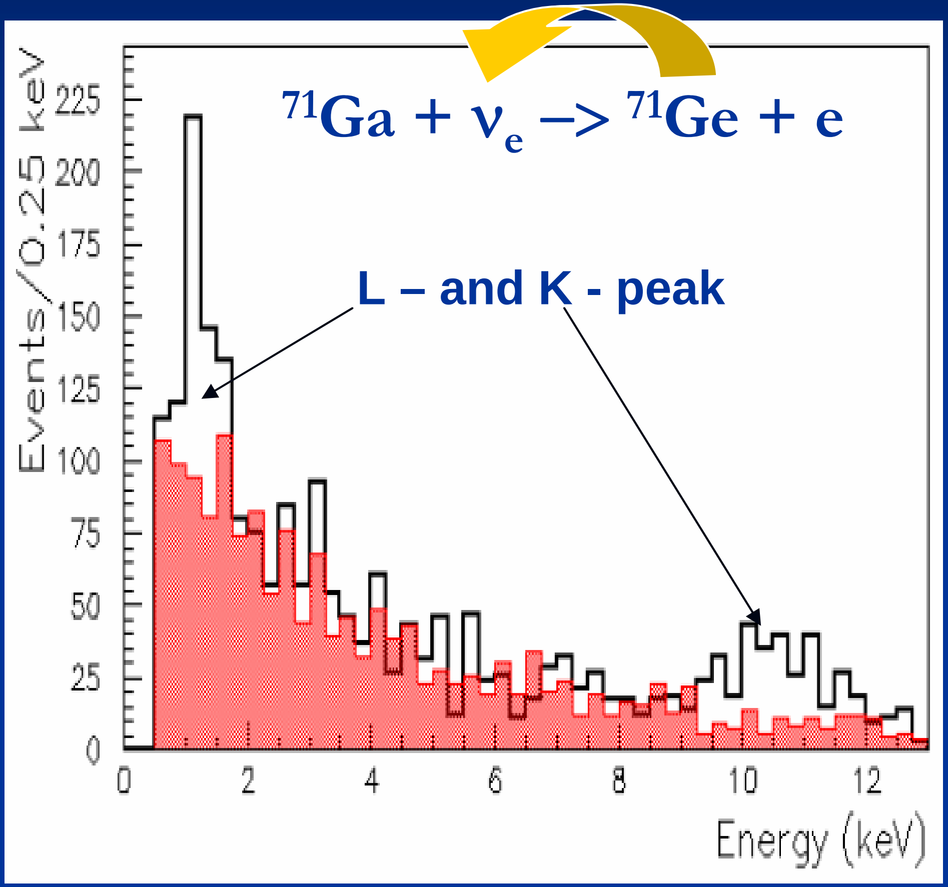
Gallex/GNO, Sage (radiochemical)

direct spectroscopy

E > 5.5 MeV

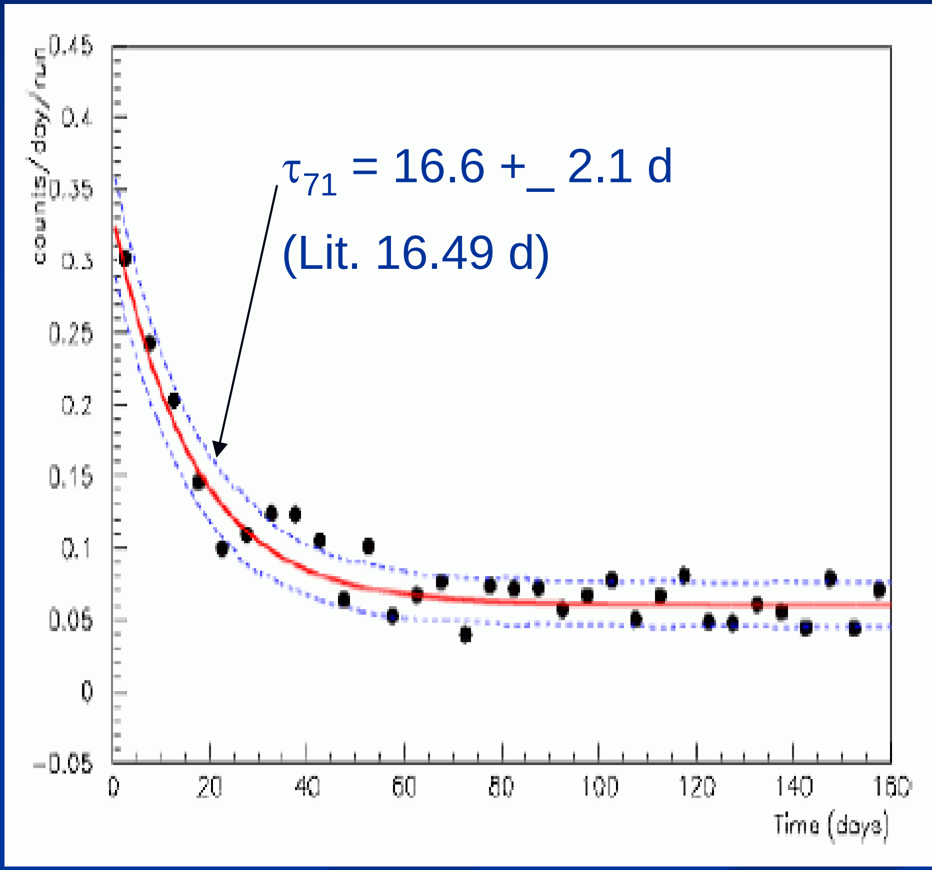
Still missing: ***low energy*** neutrino spectroscopy

Results of five years of GNO



$^{71}Ga + \nu_e \rightarrow {}^{71}Ge + e$

L – and K - peak



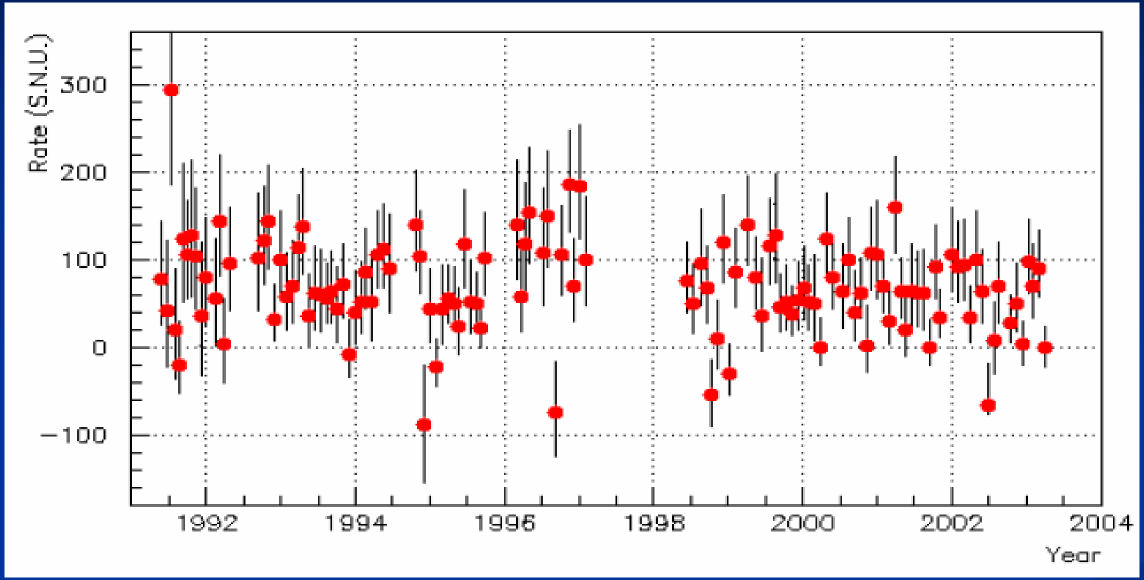
τ_{71} = 16.6 +_ 2.1 d

(Lit. 16.49 d)

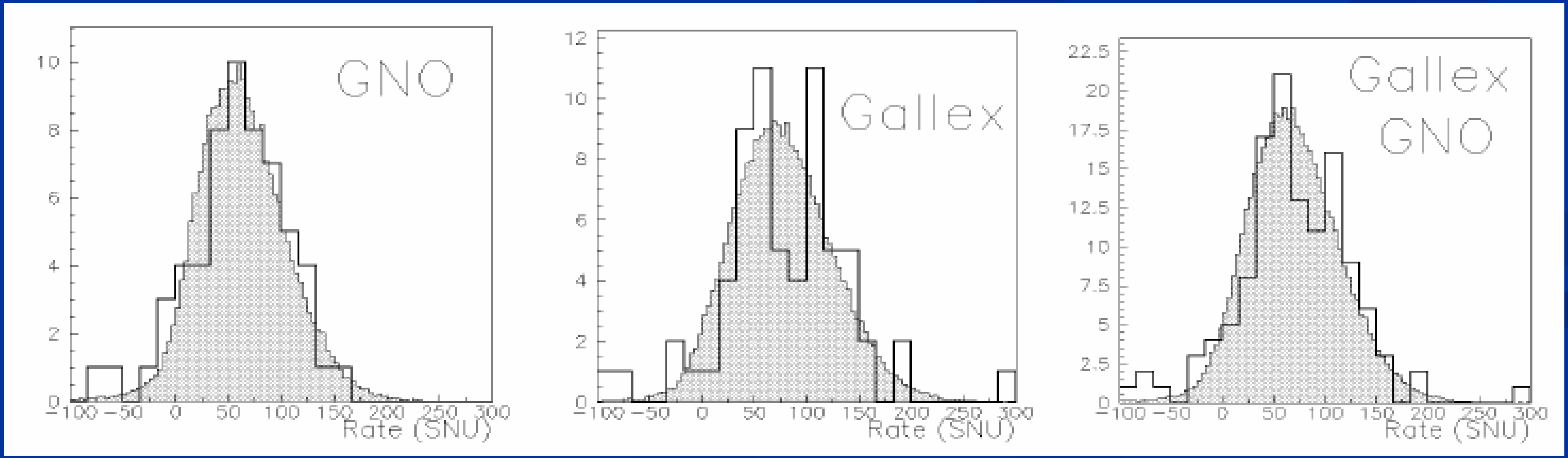
Energy spectrum Ge- electron capture

Time spectrum

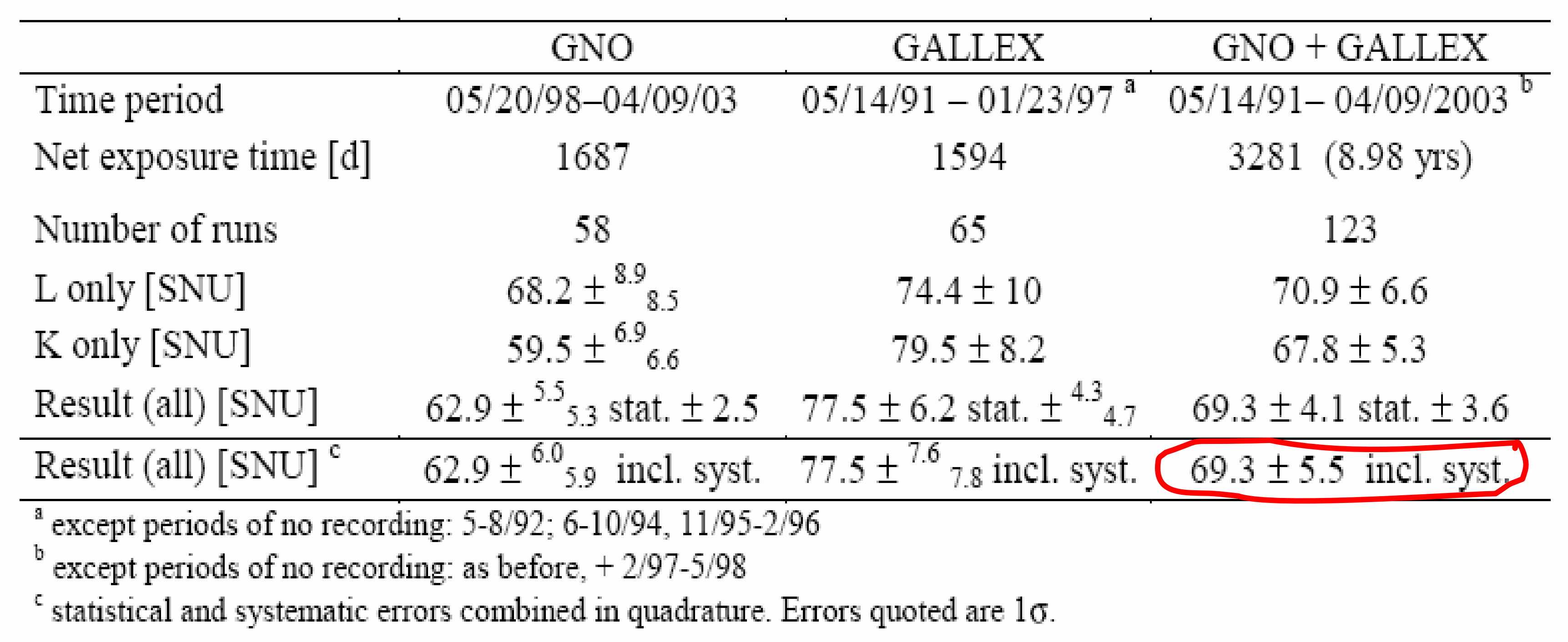
Results of five years of GNO



- Full solar cycle
- compatible with flat distribution
- slight time drift not excluded
- gaussian distributions



Combined GALLEX/GNO result



	GNO	GALLEX	GNO + GALLEX
Time period	05/20/98–04/09/03	05/14/91 – 01/23/97 [a]	05/14/91– 04/09/2003 [b]
Net exposure time [d]	1687	1594	3281 (8.98 yrs)
Number of runs	58	65	123
L only [SNU]	$68.2 \pm ^{8.9}_{8.5}$	74.4 ± 10	70.9 ± 6.6
K only [SNU]	$59.5 \pm ^{6.9}_{6.6}$	79.5 ± 8.2	67.8 ± 5.3
Result (all) [SNU]	$62.9 \pm ^{5.5}_{5.3}$ stat. ± 2.5	77.5 ± 6.2 stat. $\pm ^{4.3}_{4.7}$	69.3 ± 4.1 stat. ± 3.6
Result (all) [SNU] [c]	$62.9 \pm ^{6.0}_{5.9}$ incl. syst.	$77.5 \pm ^{7.6}_{7.8}$ incl. syst.	69.3 ± 5.5 incl. syst.

[a] except periods of no recording: 5-8/92; 6-10/94, 11/95-2/96

[b] except periods of no recording: as before, + 2/97-5/98

[c] statistical and systematic errors combined in quadrature. Errors quoted are 1σ.

- reduction of statistical and systematical uncertainties
- supression factor for low-E neutrinos (pp and ^{7}Be): P = 0.556 +_ 0.071
- L(CNO) / L(sun) < 6.5 % (3 sigma)

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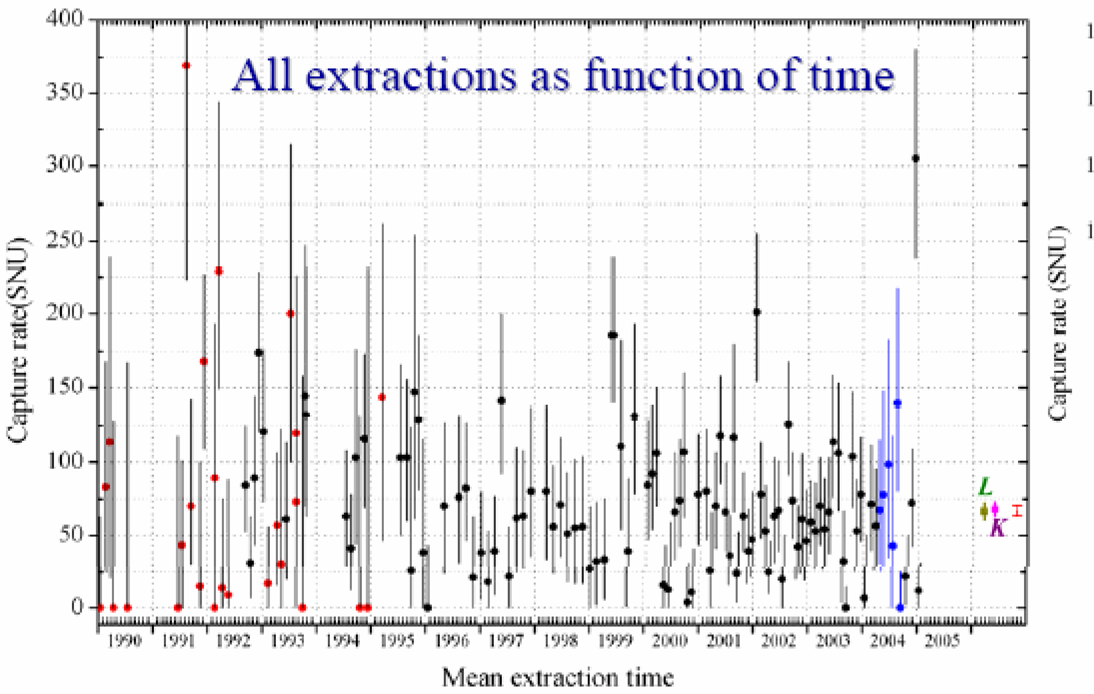
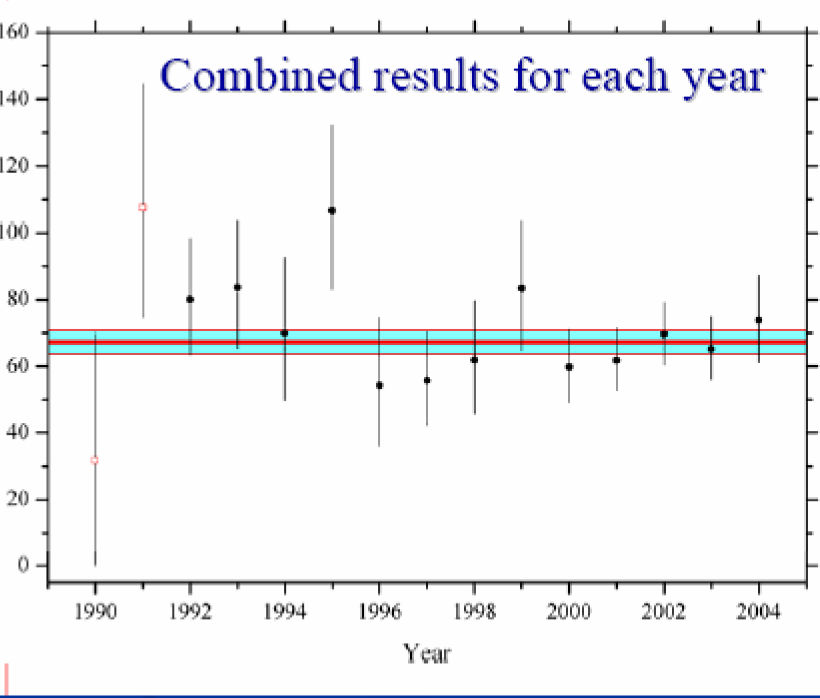
Results from SAGE





- 15 years of measurement (50 t)
- R = 67.2 + 5.2 – 4.8 SNU

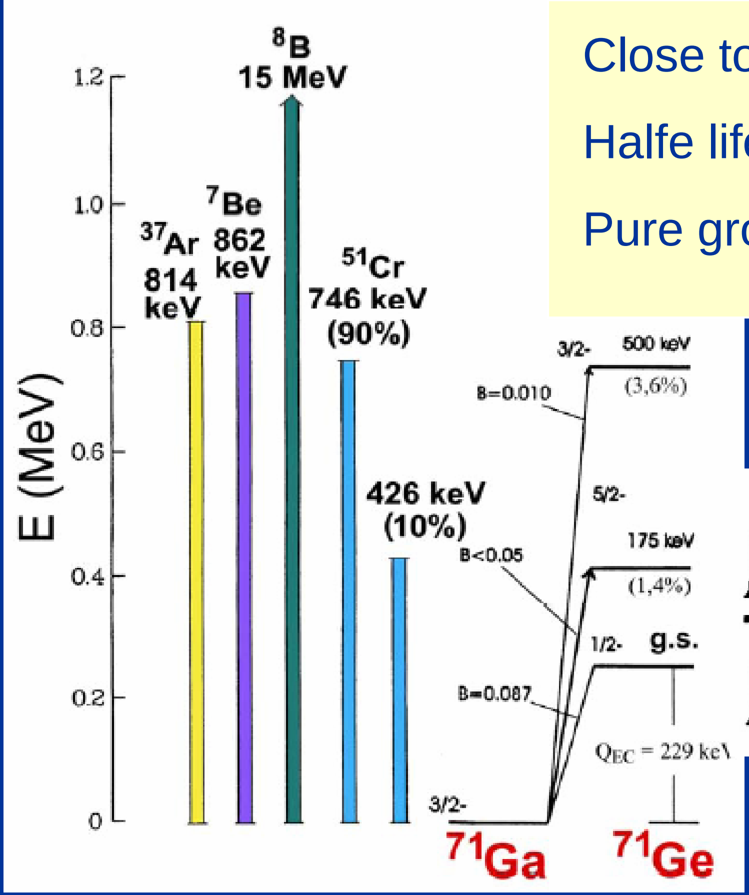
Results from SAGE

- New test of Ga neutrino cross section with ^{37}Ar

Close to ^{7}Be solar neutrino energy

Halfe life time 35 d

Pure ground state transition (^{37}Ar + e -> ^{37}Cl + ν_e)

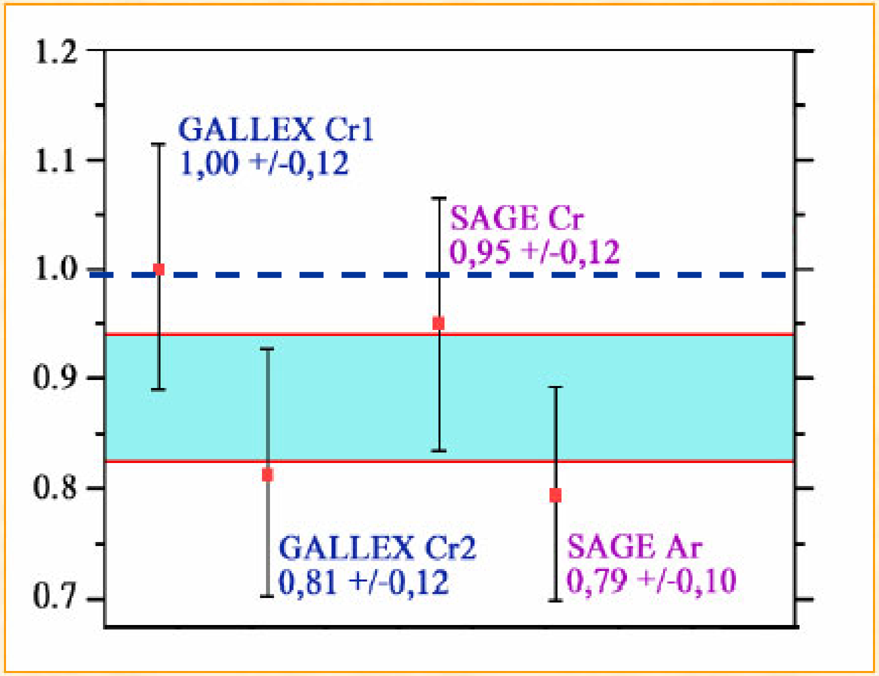


$$\frac{p_{\text{measured}}}{p_{\text{predicted}}} = \frac{11.0^{+1.0}_{-0.9}\,(\text{stat}) \pm 0.6\,(\text{syst})}{13.9^{+1.0}_{-0.4}} = 0.79^{+0.09}_{-0.10}$$

Cross section ^{71}Ga (ν,e)^{71}Ge ?

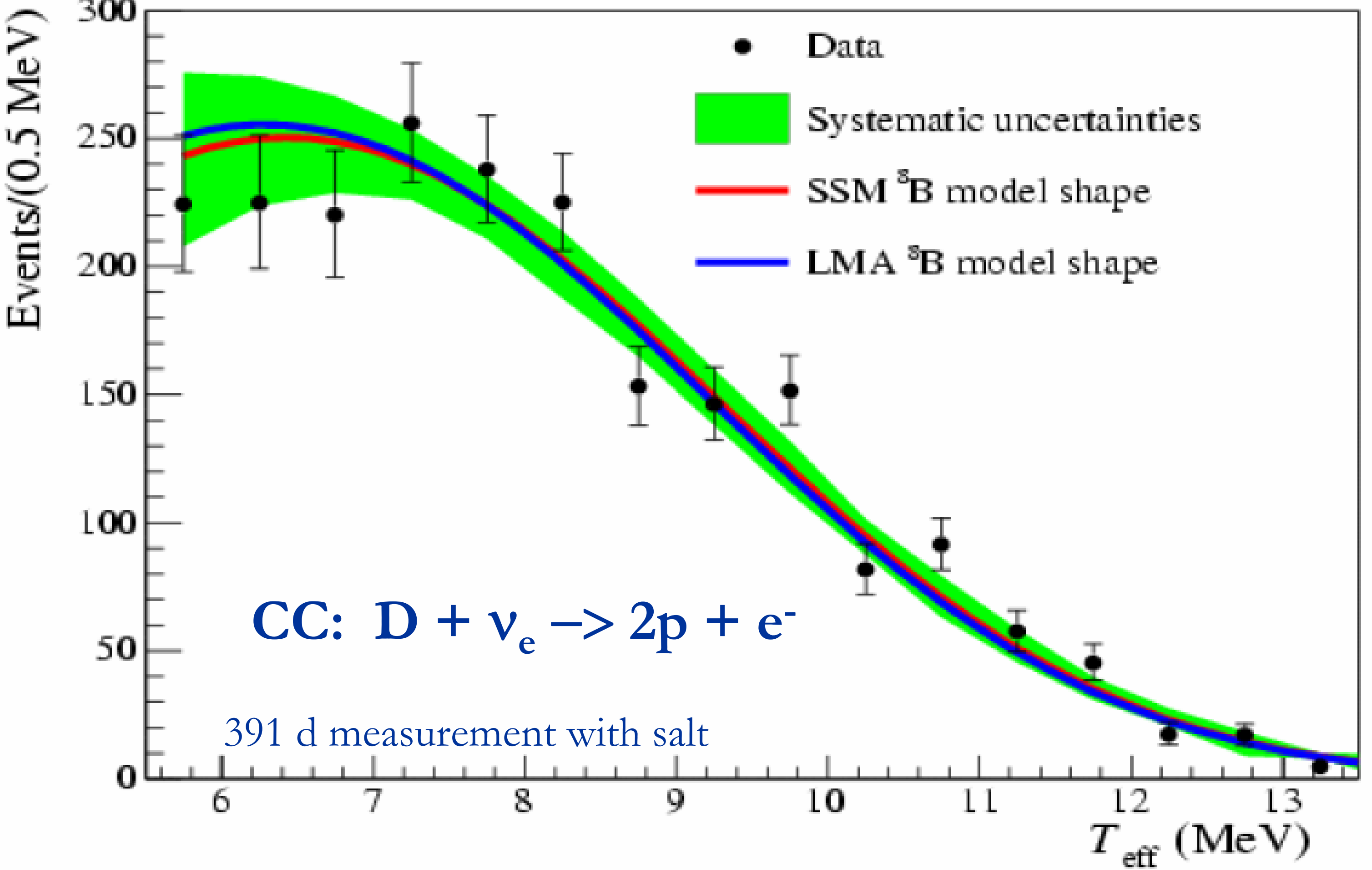
- Cr and Ar measurements combined
- Is there a problem ?

The weighted average value of *R*, the ratio of measured to predicted ^{71}Ge production rates, is 0.88 ± 0.05, more than two standard deviations less than unity.



SNO results

New Information: Charged Current Energy Spectrum

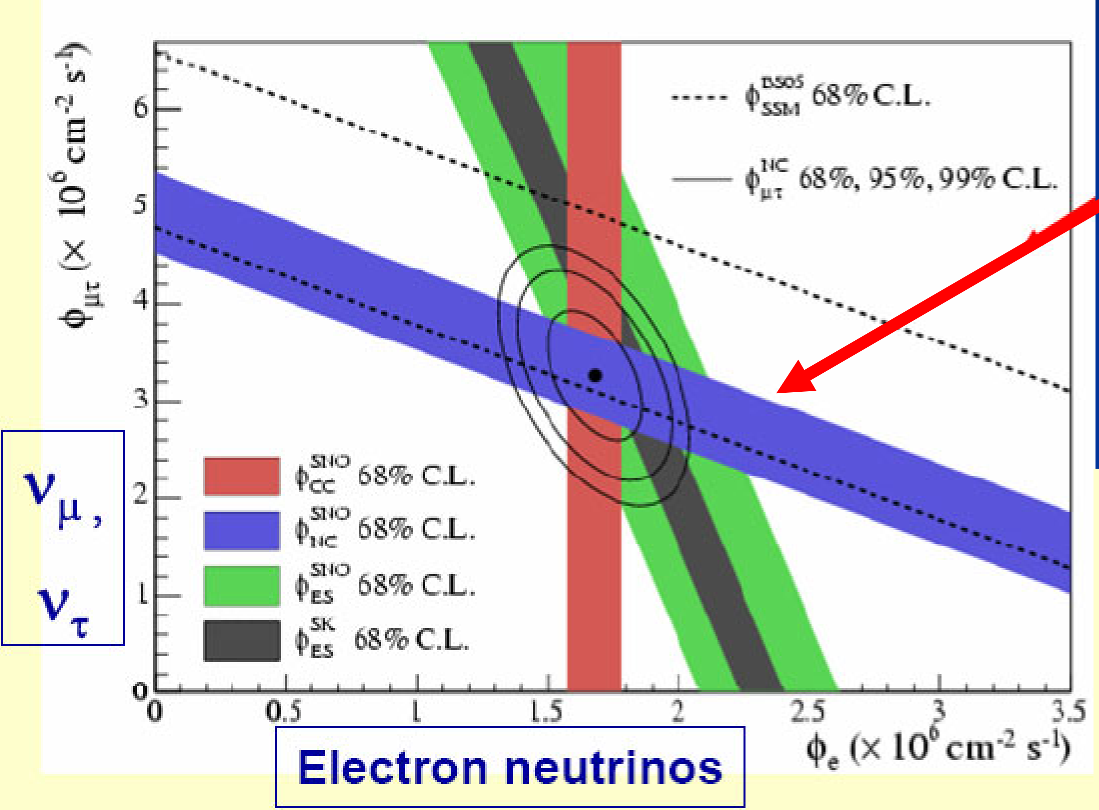


CC: D + ν_e –> 2p + e^-

391 d measurement with salt

hep-ex/0502021

SNO results



ν_μ, ν_τ

Electron neutrinos

- Flavor transition proven by 7 sigma
- Agreement with solar models

$$\phi_{CC} = 1.68 \; {}^{+0.06}_{-0.06}(\text{stat.})^{+0.08}_{-0.09}(\text{syst.})$$

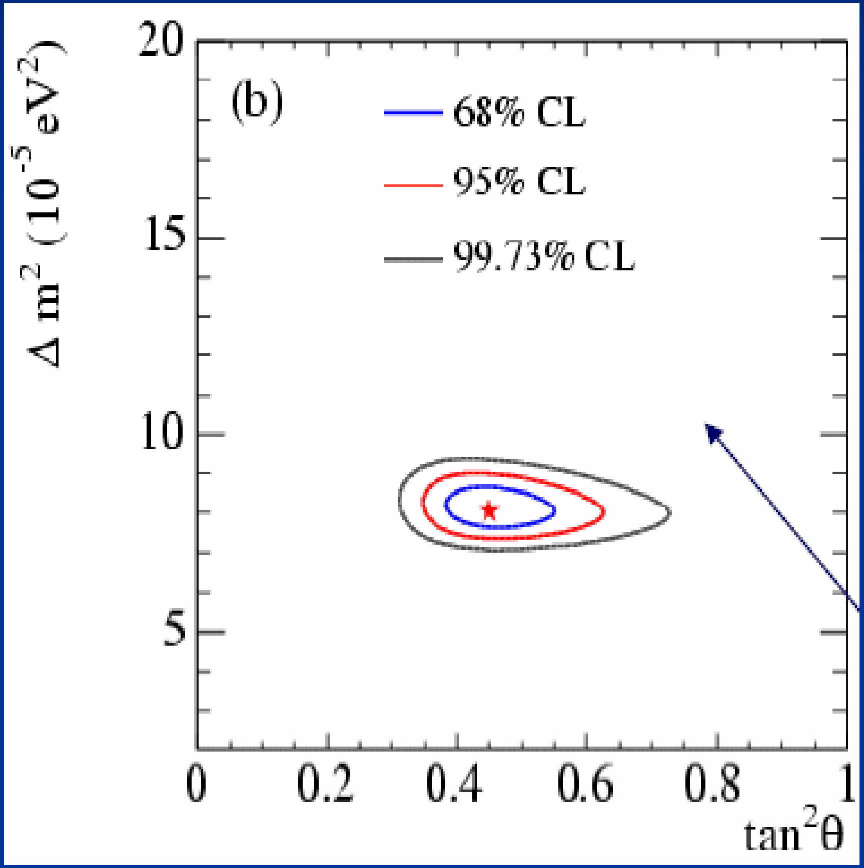
$$\phi_{NC} = 4.94 \; {}^{+0.21}_{-0.21}(\text{stat.})^{+0.38}_{-0.34}(\text{syst.})$$

$$\phi_{ES} = 2.35 \; {}^{+0.22}_{-0.22}(\text{stat.})^{+0.15}_{-0.15}(\text{syst.})$$

(In units of $10^6\,\text{cm}^{-2}\text{s}^{-1}$)

NC: $D + \nu_x \rightarrow p + n + \nu_x$

SNO results



- Improved accuracy on Θ_{12}
- Non maximum mixing by 5 sigma
- LMA-solution: very small spectral deformation, day/night ~3% ok with SNO and SK data

Prospects

- **Low energy neutrino spectroscopy: ^{7}Be, pp, pep, CNO**
- Detailed information about thermal fusion processes
- ^{7}Be: a 10% measurement yields determination of pp-flux with < 1% uncertainty
- pp, pep: yields present solar luminosity
- CNO: important for massive stars
- Matter effects: improve sensitivity on mixing parameter, looking for new effects

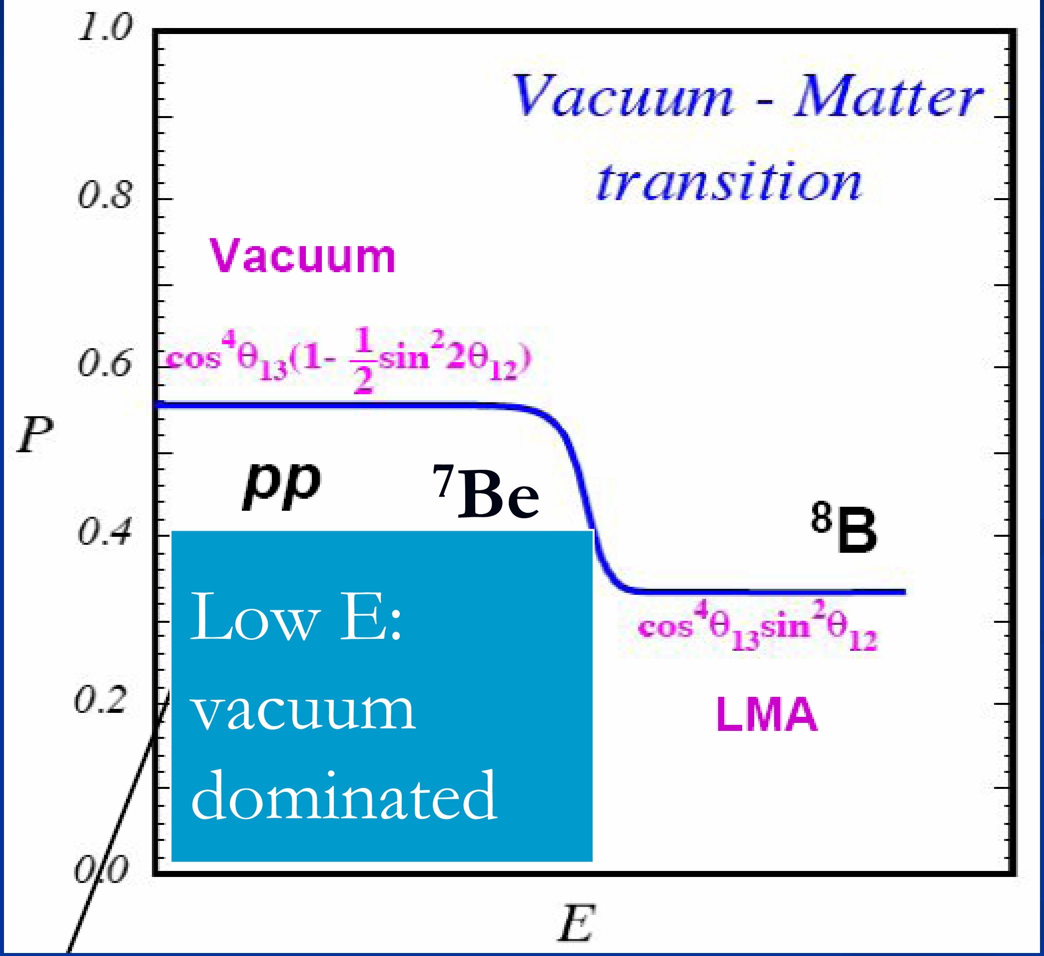
CNO

- New value of $^{14}N(p,\gamma)^{15}O$ cross section (LUNA)
- New measurements metal/hydrogen on solar surface: from 0.023 to now 0.0176
- Consequence 1: CNO – ν flux goes down to 50-70%
- Consequence 2: **Age** of **globular clusters** increases by **0.7 to 1 Gy** !
- Consequence 3: Depth convective zone $R_{cz}/R_0 = 0.726$

  …but helioseismology says $R_{cz}/R_0 = 0.713 +\_ 0.001$!

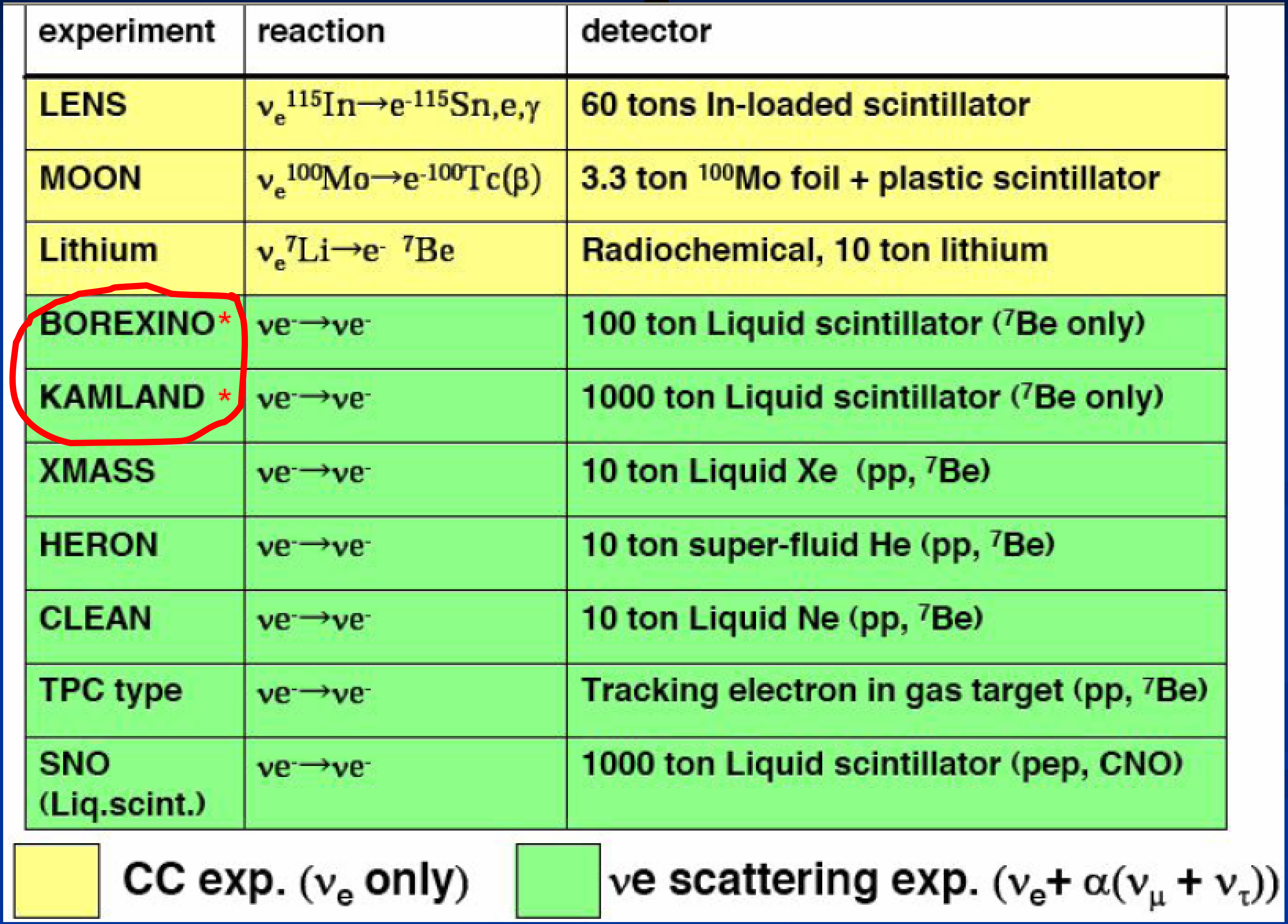
- Direct measurement of CNO – neutrinos required !

Matter effects



- Confirm matter effect (determines mass hierarchy $m_2>m_1$) with low E solar neutrinos
- Improve Θ_{12}, Θ_{13}
- Search for non-standard effects: sterile neutrinos, new interactions

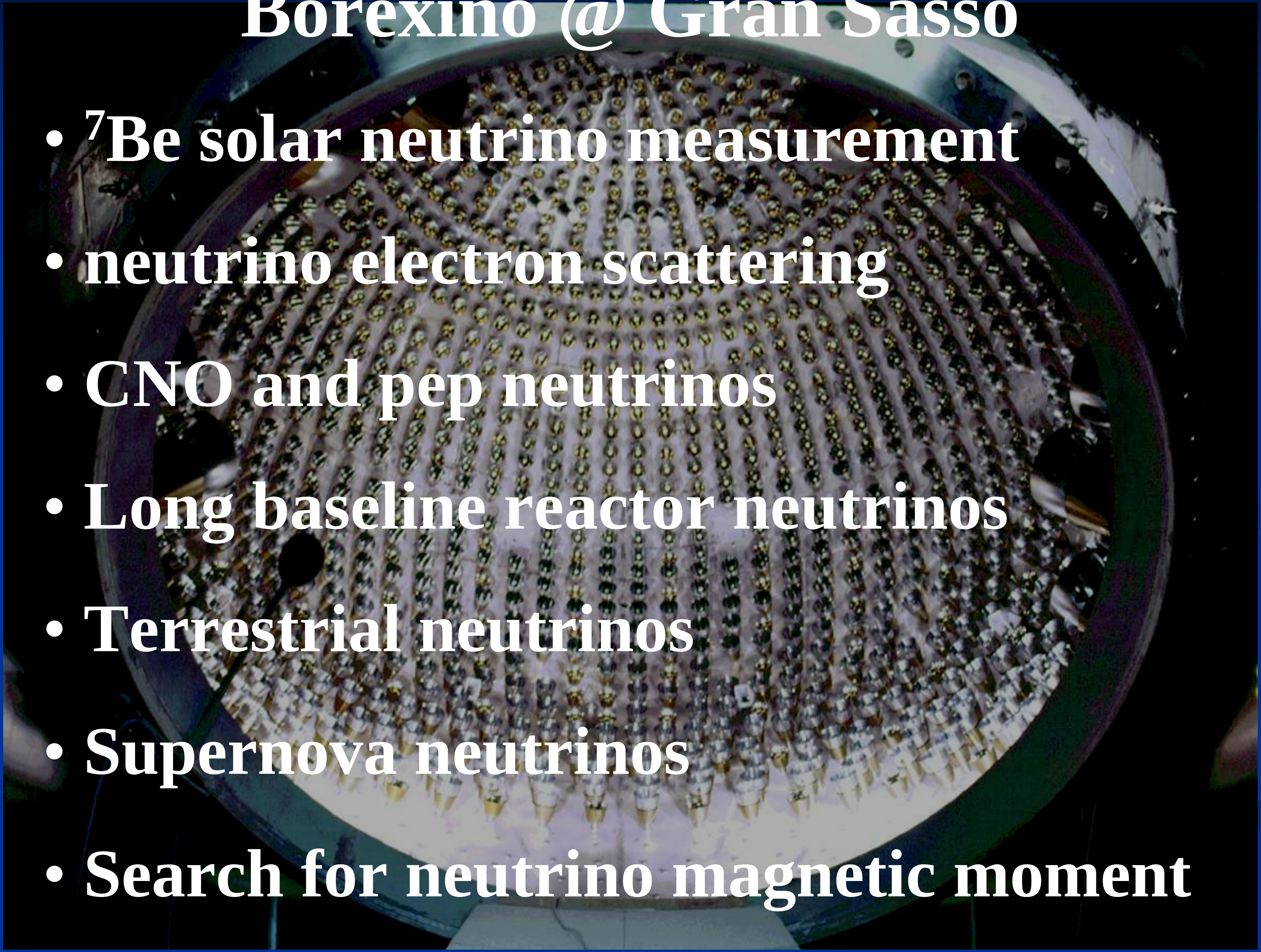
Future experiments



experiment	reaction	detector
LENS	$\nu_e {}^{115}In \to e^- {}^{115}Sn, e, \gamma$	60 tons In-loaded scintillator
MOON	$\nu_e {}^{100}Mo \to e^- {}^{100}Tc(\beta)$	3.3 ton ^{100}Mo foil + plastic scintillator
Lithium	$\nu_e {}^{7}Li \to e^- \ {}^{7}Be$	Radiochemical, 10 ton lithium
BOREXINO*	$\nu e^- \to \nu e^-$	100 ton Liquid scintillator (^7Be only)
KAMLAND *	$\nu e^- \to \nu e^-$	1000 ton Liquid scintillator (^7Be only)
XMASS	$\nu e^- \to \nu e^-$	10 ton Liquid Xe (pp, ^7Be)
HERON	$\nu e^- \to \nu e^-$	10 ton super-fluid He (pp, ^7Be)
CLEAN	$\nu e^- \to \nu e^-$	10 ton Liquid Ne (pp, ^7Be)
TPC type	$\nu e^- \to \nu e^-$	Tracking electron in gas target (pp, ^7Be)
SNO (Liq.scint.)	$\nu e^- \to \nu e^-$	1000 ton Liquid scintillator (pep, CNO)

🟨 CC exp. (ν_e only) 🟩 νe scattering exp. ($\nu_e + \alpha(\nu_\mu + \nu_\tau)$)

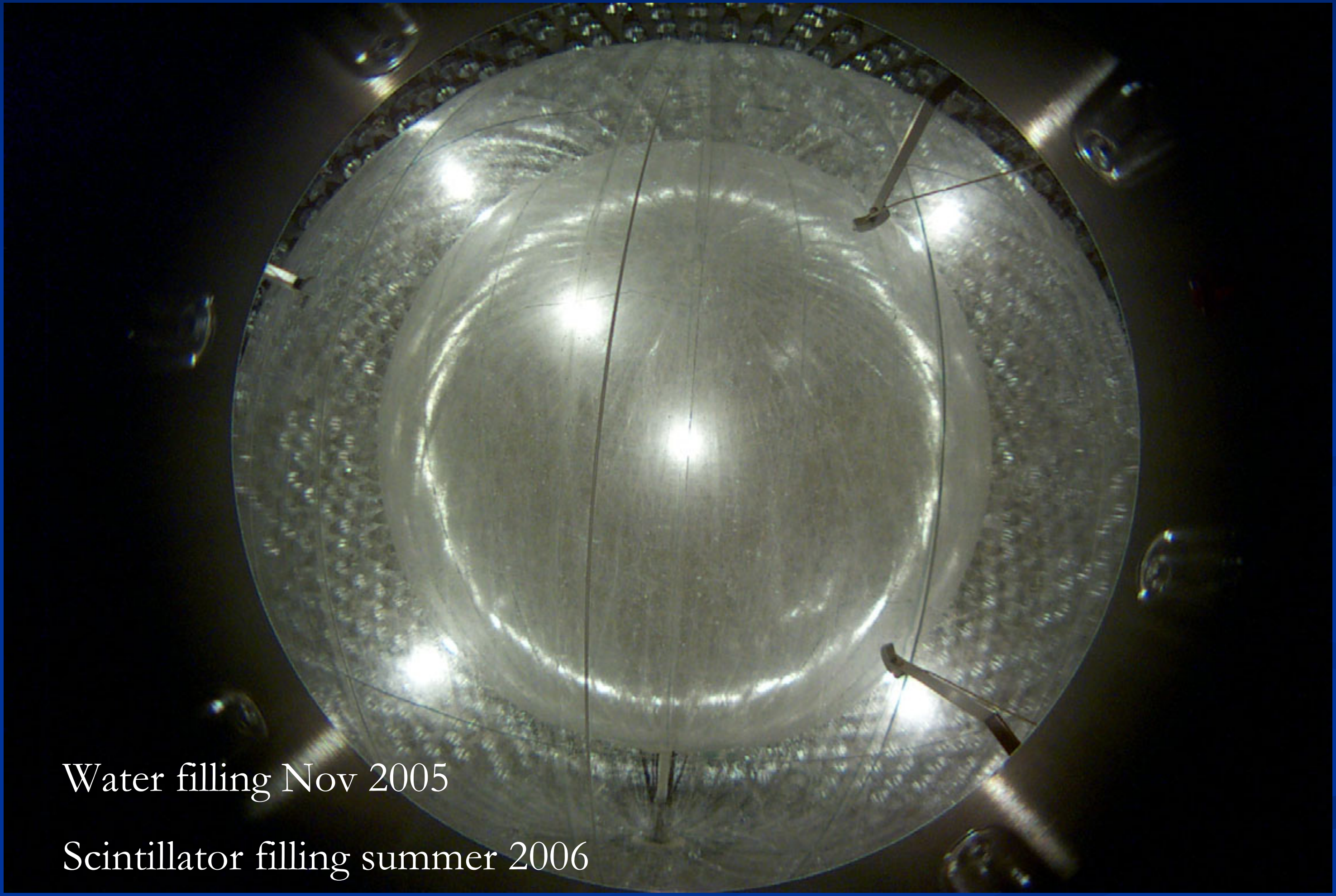
Borexino @ Gran Sasso



- ^{7}Be solar neutrino measurement
- neutrino electron scattering
- CNO and pep neutrinos
- Long baseline reactor neutrinos
- Terrestrial neutrinos
- Supernova neutrinos
- Search for neutrino magnetic moment

Borexino

Inner Vessel Installation completed in 2004



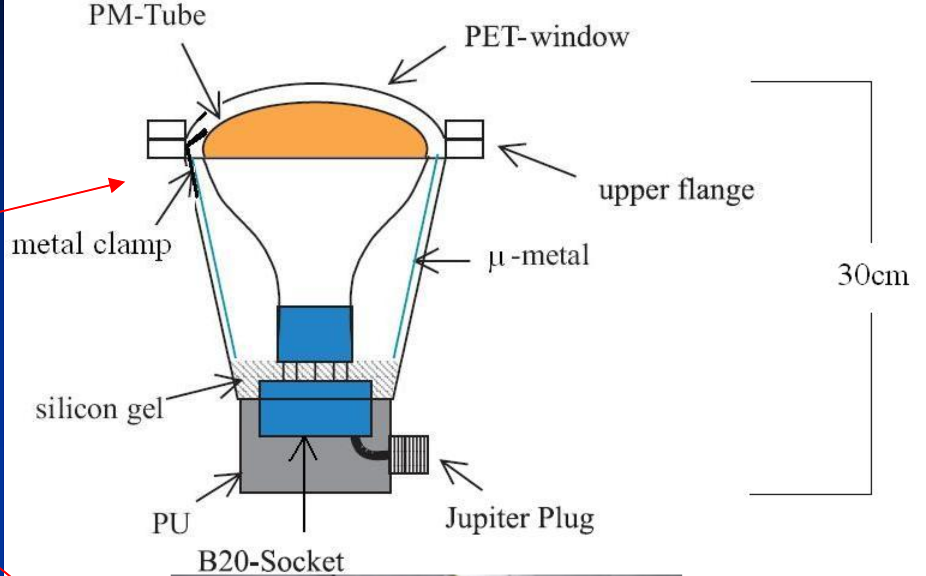
Water filling Nov 2005

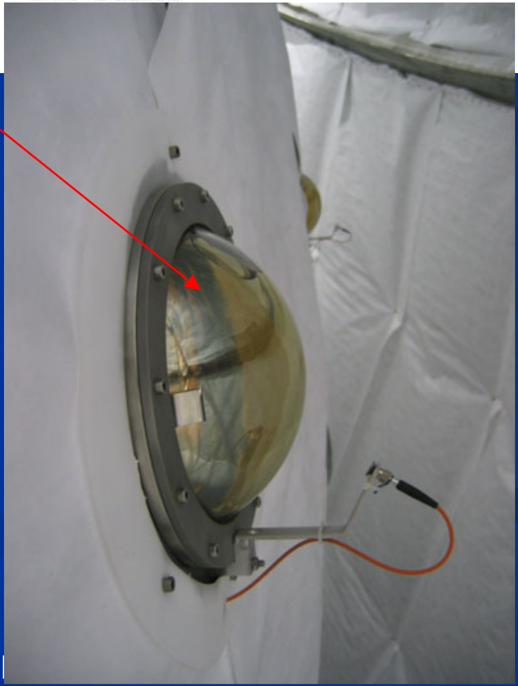
Scintillator filling summer 2006

Borexino muon veto system

208 encapsulated PMs (window with wavelength shifter)

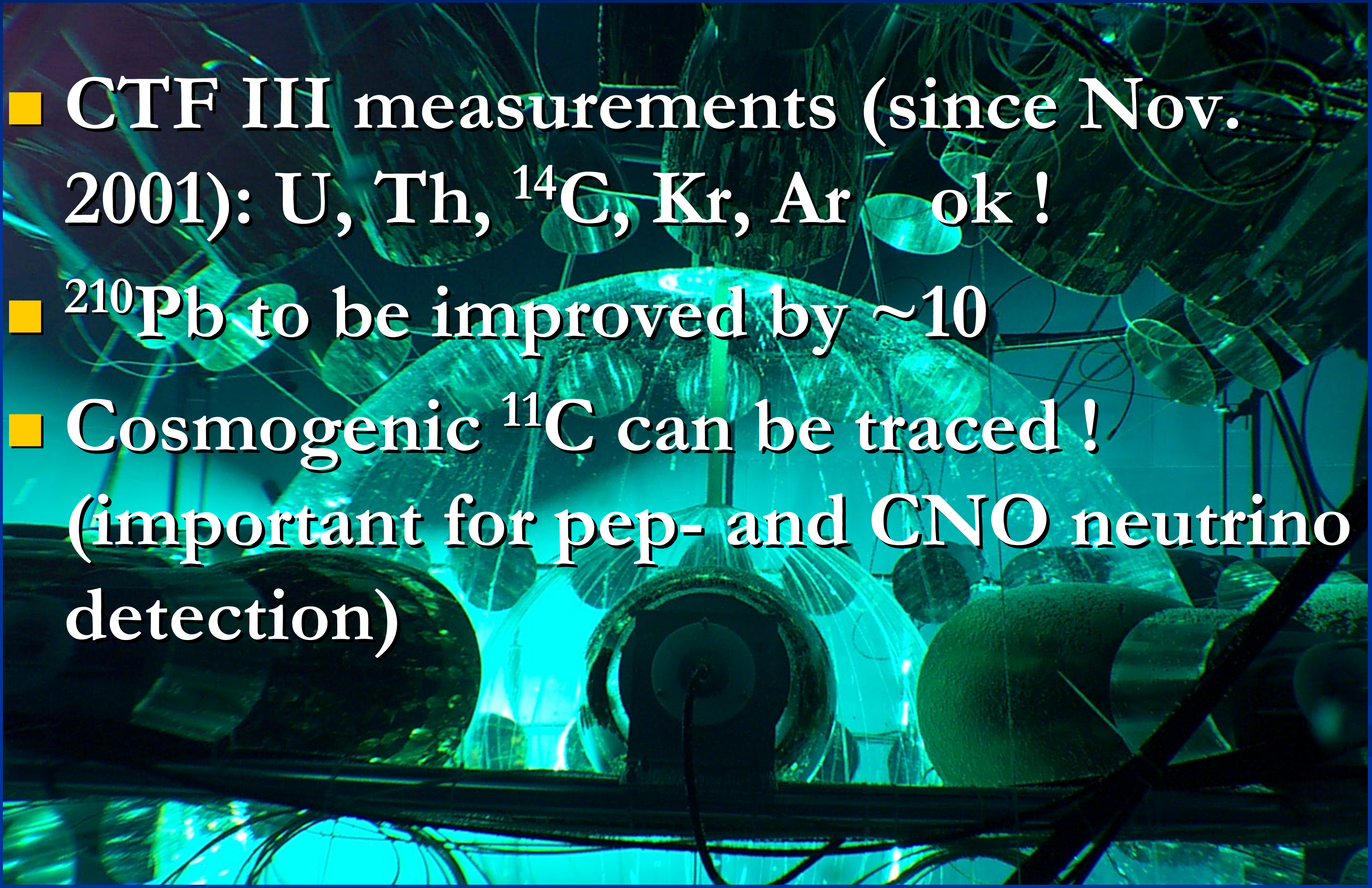
Tyvek reflector sheets





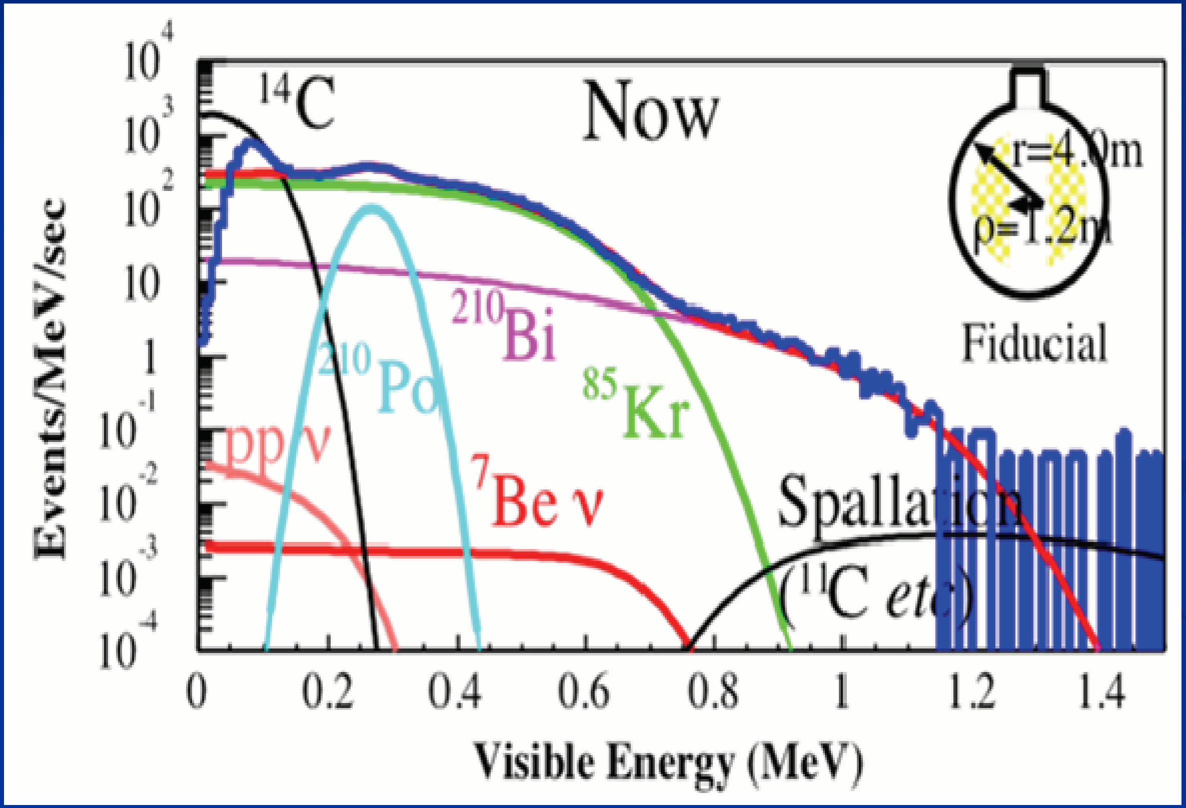
Thanks to: MLL, VIDMAN

Borexino Background



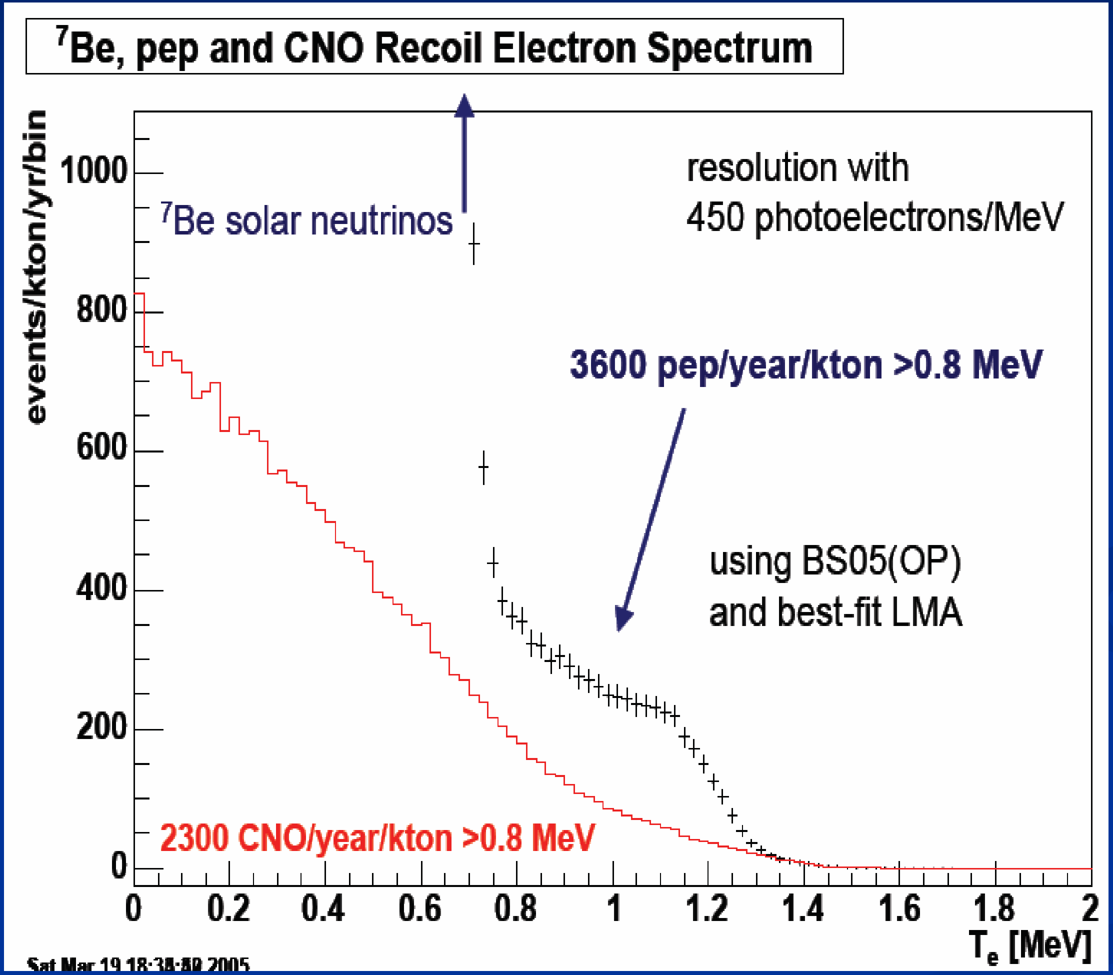
- CTF III measurements (since Nov. 2001): U, Th, ^{14}C, Kr, Ar ok !
- ^{210}Pb to be improved by ~10
- Cosmogenic ^{11}C can be traced ! (important for pep- and CNO neutrino detection)

KamLAND solar neutrino phase



- Kr: 10^6 to high
- ^{210}Pb (and daughters): 10^5
- Cosmogenic bg x 7 compared to Borexino
- R&D phase (distillation)
- 6 M$ invest. System installation summer 2006

SNO+



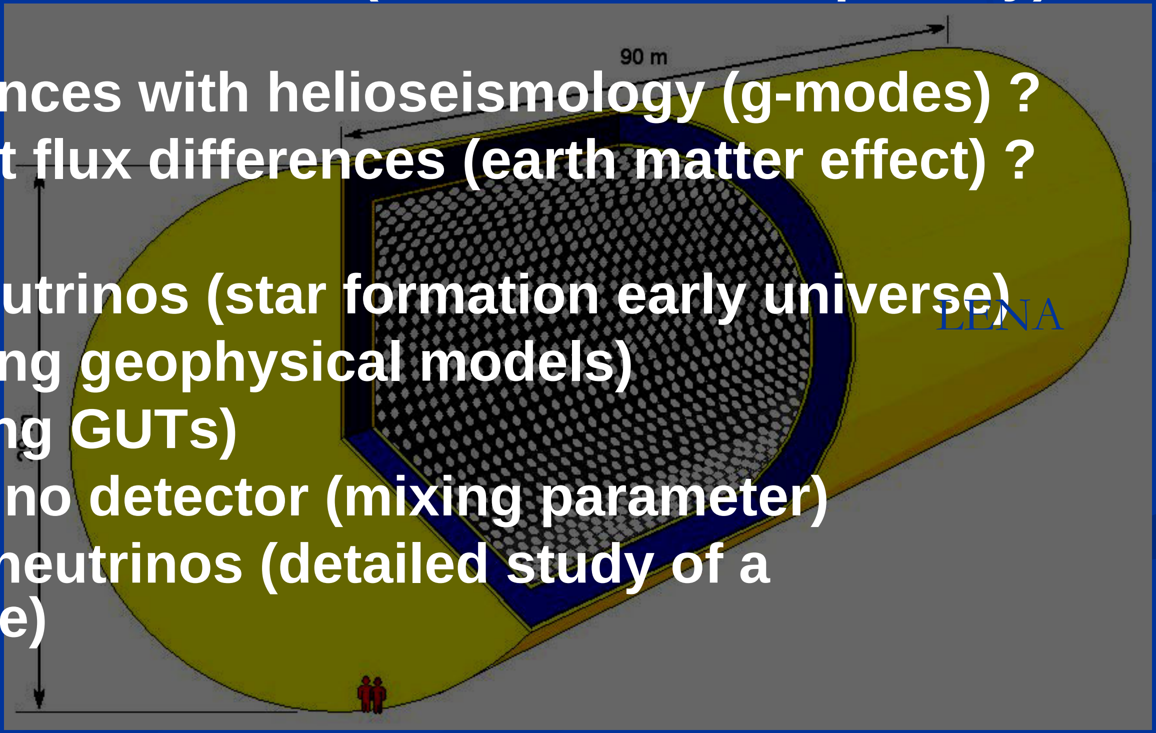
- Liquid scintillator 1kt (after heavy water period)
- Muon rate ~ 70 / d (KamLAND 26 x 10^3 /d)
- Hence low ^{11}C background
- Pep + CNO

Future large scintillation detectors

- LENA (Low Energy Neutrino Astronomy)
  ~ 50 kt, CUPP, Finland
- HSD (Hyper Scintillation Detector) ~50 kt, USA
- Baksan ~ 30 kt

Solar neutrino physics

- flux variations in time (~5400 Be-events per day)
  ?
- coincidences with helioseismology (g-modes) ?
- day/night flux differences (earth matter effect) ?



- Relic supernovae neutrinos (star formation early universe)
- Geoneutrinos (probing geophysical models)
- Proton decay (probing GUTs)
- Long baseline neutrino detector (mixing parameter)
- Galactic supernova neutrinos (detailed study of a gravitational collapse)

Conclusions

- Low energy neutrino physics successfull
- Neutrino oscillations
- Much more insight into thermal nuclear fusion
- Future: low energy solar neutrino spectroscopy
- Neutrino parameter (matter effects)
- ^{7}Be, CNO, pep – neutrinos
- Technology allows to aim for ~50 kt detectors